Application of Multi-Criteria Decision-Making Methods in Supplier Selection

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Abstract
The problem of supplier selection is significant in the defense industry, as in all sectors, for companies to carry out their production in a healthy way and to deliver products on time. Since the defense industry is a critical sector that directly regarding the country's security, fast and safe supply is directly related to the country's defense. This study discusses the selection problem of the suppliers used for the surface processing of the parts of a company operating in the defense industry. Expert decision-makers evaluate the criteria determined, and it is aimed to select the most suitable supplier with Fuzzy AHP (Analytic Hierarchy Process) and Fuzzy TOPSIS methods.

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1. INTRODUCTION

Businesses must establish an effective supplier management system to ensure continuity in increasingly competitive conditions. Supply management encompasses all processes from raw material supply to the final product stage. The performance exhibited in these processes significantly contributes to ensuring the enterprises' continuity. Several factors, such as quality, time, and price, influence the decision-making process for selecting suppliers. There are numerous criteria involved in exploring alternative suppliers to enhance the business potential of enterprises (Özçelik & Eryılmaz, 2019). Supplier selection criteria vary based on the sector and product structure of the enterprises. The multitude of criteria impacting the selection process, along with the growing number of suppliers, contributes to the complexity of the supplier selection problem (Deste & Serve, 2021). The selection of a supplier forms the basis for predicting and evaluating partnership-building capabilities for supplier collaboration. Companies should implement appropriate supplier selection strategies to identify potential partners in the globalizing world order (Hsu et al., 2013). The presence of diverse expert decision-makers and a variety of criteria has led to the utilization of Multiple Criteria Decision Making (MCDM) techniques in addressing the selection problem.
Numerous studies in supplier selection utilize multi-criteria decision-making methods. Karabayır and Botsalı (2022) identified seven primary criteria and twenty-four sub-criteria for selecting suitable suppliers in the construction industry. They applied Fuzzy AHP to weigh decision criteria and Fuzzy TOPSIS to list alternatives. To and Kritchanchai (2022) employed the Fuzzy TOPSIS method to

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select sustainable suppliers for a hospital, conducting sensitivity analysis to validate their results. Gupta (2022) utilized the fuzzy AHP-TOPSIS method for supplier selection in the Indian automobile industry, highlighting economic sustainability as the paramount criterion. Arslankaya and Çelik (2021) utilized Fuzzy AHP and Fuzzy MOORA methods to determine green criteria for steel sheet raw material suppliers in the steel door manufacturing sector.

Tsai and Phumchusri (2021) employed Fuzzy AHP in selecting raw material suppliers for a nano SIM card connector manufacturer. Kılınçcı and Önal (2011) used Fuzzy AHP for supplier selection of the washing machine company. Çakar and Çavuş (2021) utilized the Fuzzy TOPSIS method to choose suppliers for Sütaş Süt, newly entered into the Macedonian milk market.Astanti et al. (2020) employed various versions of Fuzzy AHP for supplier selection in the glove manufacturing industry in Indonesia. Özen and Borat (2020) used the IATF 16949:2016 standard and risk analysis in selecting suppliers for an automotive supplier industry company, conducting sensitivity analyses with AHP, Fuzzy AHP, and Fuzzy TOPSIS methods.

Javad et al. (2020) used BWM and Fuzzy TOPSIS methods to select suppliers based on their green innovation capabilities in a steel company. Manivel and Ranganathan (2019) utilized Fuzzy AHP and Fuzzy TOPSIS methods for hospital pharmacy supplier selection, categorizing criteria into Supplier, Product Performance, and Service Performance dimensions.Galankashi et al. (2016) applied the Balanced Scorecard–Fuzzy Analytic Hierarchical Process (BSC–FAHP) model in the automobile industry, proposing a new BSC model while evaluating four suppliers across different perspectives. Awasthi et al. (2017) employed the Fuzzy AHP-Fuzzy VIKOR integrated method, identifying economic, quality, environmental, social, and global risk sustainability criteria.Deshmukh and Vasudevan (2019) determined eight primary criteria and forty sub-criteria, both traditional and green, for supplier selection in plastic manufacturing. Mondragon et al. (2019) aimed to use AHP and Fuzzy AHP methods for technology and supplier selection in the textile industry, based on twelve criteria for production technology. Azimifard et al. (2018) utilized AHP and TOPSIS methods in the Iranian steel industry

In this study, Fuzzy AHP and Fuzzy TOPSIS methods were used by considering the surface process supplier selection problem of a company operating in the defense industry. It aims to select the most suitable supplier by considering four alternatives in line with the ten criteria. After expert decision-makers evaluated the criteria, the alternatives were assessed according to these criteria. The fundamental aim of this research is to investigate the utilization of Fuzzy AHP and Fuzzy TOPSIS methodologies in supplier selection within the academic literature, thereby contributing to the existing body of knowledge. The structure of this study encompasses four distinct sections. Section 1 explores the inherent significance of the supply chain. Section 2 elucidates the methodologies employed in this study. Transitioning to Section 3, a comprehensive analysis of the practical application of these methodologies is presented. Finally, Section 4 encapsulates the conclusive findings of the study, concurrently highlighting gaps in the current literature and suggesting potential avenues for future research.

2. MATERIAL AND METHOD

The methods used are discussed in detail in this section.

2.1. Fuzzy AHP

Chang's extended analysis method consists of 4 steps (Chang, 1996).

Step 1: The linguistic variables of the decision makers were converted into triangular fuzzy numbers using the scale in Table 1.

Table 1. Fuzzy analytical hierarchy process importance scale and definition

Absolutely More Important	(3.5, 4, 4.5)
Very Strongly More Important	(2.5, 3, 3.5)
Strongly More Important	(1.5, 2, 2.5)
Weakly More Important	(0.66, 1, 1.5)
Just Equal	(1, 1, 1)
Weakly More Important	(0.66, 1, 1.5)
Not Strongly More Important	(0.4, 0.5, 0.66)
Very Weakly More Important	(0.285, 0.33, 0.4)
Not Absolutely Important	(0.22, 0.25,0.285)

The fuzzy synthetic extent value for criterion i is calculated using Equation (1).

$$Si = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (1)$$

The fuzzy value of Si in the equation represents the synthesis value of i. purpose, M_{gi}^{j} represents the expanded value for all purposes. $\sum_{j=1}^{m} M_{gi}^{j}$ value is obtained by fuzzy addition in Equation (2).

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (2)$$

Then $[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]$ value is obtained by fuzzy addition in Equation (3).

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{m} l_i, \sum_{i=1}^{m} m_i, \sum_{i=1}^{m} u_i\right) \quad (3)$$

To find $[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]^{-1}$ the inverse of the vector is calculated with the help of Equation (4).

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i}^{n} ui}, \frac{1}{\sum_{i=1}^{n} mi}, \frac{1}{\sum_{i=1}^{n} li}\right) \quad (4)$$

Step 2: Calculated synthesis values are compared, and weight values are calculated from these values. The possibility degree of equality of two fuzzy numbers ($M2 \geq M1$) with $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is calculated according to Equation (5).

$$V(M_2 \geq M_1) = sup_{y \geq x} [\min \mu M_1 (x), \mu M2 (y)] \quad (5)$$

The membership function equation is expressed as in Equation (6).

$$V(M_2 \geq M_1) = \begin{cases} 1 & , \quad m2 \geq m1 \\ 0 & , \quad l1 \geq u2 \\ \frac{l1-u2}{(m2-u2)-(m1-l1)} & , \quad \text{otherwise} \end{cases} \quad (6)$$

In V ($M_2 \geq M_1$), the intersection point d, μM_1 and μM_2 equals the ordinate of the d point. The point "d" here is the ordinate of the largest intersection point. The graphical representation of the comparison is shown in Figure 1 (Kaptanoğlu and Özok, 2006).

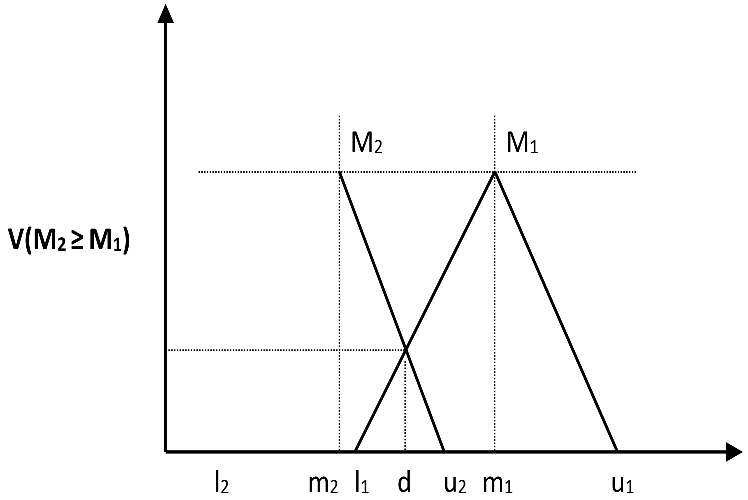

Figure 1. M1 and M2 intersection point

Step 3: The possibility degree of a convex fuzzy number greater than Mi (i = 1,2, . . . , k) values out of k convex fuzzy numbers is expressed as in Equation (7).

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{and } (M \geq M_k) = \min V(M \geq Mi)$$

$$(i = 1,2, \ldots, k) \quad (7)$$

For all k values k = 1, 2, . . . , Assuming, n and k ≠ i, $d'(Ai) = \min V(S_i \geq S_k)$ the weight vector is calculated according to Equation (8). A_i (i = 1,2, . . . , n) n elements.

$$W' = (d'(A_1), d'(A_2) \ldots . d'(A_n))^T \quad (8)$$

Step 4: Normalization is performed by adding all the elements of the vector and dividing each element by this sum. With the normalization process, the weight vector is obtained as normalized as in Equation (9). W is a non-fuzzy number of real numbers.

$$W = (d(A_1), (A_2), \ldots, (A_n))^T \quad (9)$$

2.2. Fuzzy TOPSIS

Chen (2000) will explain the step-by-step algorithm of the Fuzzy TOPSIS method.

Step 1: The linguistic variables of the criteria and alternatives are converted into triangular fuzzy numbers using Table 2.

Table 2. Linguistic variables for the criteria and alternatives

Very low (VL)	(0,0,1)	(0, 0, 1)
Low (L)	(0,0.1,0.3)	(0, 1, 3)
Medium low (ML)	(0.1,0.3,0.5)	(1, 3, 5)
Medium (M)	(0.3,0.5,0.7)	(3, 5, 7)

Medium high (MH)	(0.5,0.7,0.9)	(5, 7, 9)
High (H)	(0.7,0.9,1.0)	(7, 9, 10)
Very high (VH)	(0.9,1.0,1.0)	(9, 10, 10)

In the fuzzy TOPSIS method, the triangular fuzzy number equivalent of verbal expressions is defined as r= (a; b; c). Decision makers (K) perform their evaluations among $A_1, A_2, \cdots, A_m$ alternatives, taking into account the decision criteria defined with $C = \{Ci \backslash i = 1,2,\cdots,n\}$. $\tilde{D}$ fuzzy decision matrix consists of $\tilde{x}_{ij}$ elements as shown in Equation (10), and these elements are the alternatives of $A_i (i = 1,2, \cdots, m)$ according to C_j (j = 1,2,⋯,c) criteria. W is the matrix of the decision criteria formed by the $\tilde{w}i$ elements, which indicate the importance weights of the Cj (j = 1,2,⋯,c) criteria.

$$x\tilde{i}j = \frac{1}{K}[x\tilde{i}j^{\,1} + x\tilde{i}j^{\,2} + \cdots + x\tilde{i}j^{\,K}] \tag{10}$$

$$D = \begin{bmatrix} \tilde{x}11 & \cdots & \tilde{x}1n \\ \vdots & \ddots & \vdots \\ \tilde{x}m1 & \cdots & \tilde{x}mn \end{bmatrix}$$

$$W = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]$$

The fuzzy decision matrix is normalized using Equation (11).

$$R = [\tilde{r}ij]_{mxn} \rightarrow (rij^L, rij^M, rij^U) = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right), \ i=(1,2,..,m) \ ; j \ \ j \in K_m \tag{11}$$

$$u_j^+ = max_i(u_{ij}) \quad ; \quad j \in Km \tag{12}$$

Step 2: The weighted normalized fuzzy decision matrix is calculated by Equation (13) by multiplying the importance weights of the criteria with the normalized triangular fuzzy number values.

$$V_{ij} = W_j * r_{ij} \tag{13}$$

Step 3: The fuzzy positive ideal solution is determined as $\boldsymbol{A}+$ and the fuzzy negative ideal solution as $\boldsymbol{A}-$. The values of $\boldsymbol{A}+$ of the fuzzy positive ideal solution are calculated by Equation (14) and by Equation (15).

$$V_j^+ = max_i\{V_{ij4}\} \tag{14}$$

The fuzzy positive ideal solution (A+) elements are as follows.

$$A^+ = (V_1^+, V_2^+, .., V_n^+) \tag{15}$$

The $A-$ values for the fuzzy negative ideal solution are calculated by Equation (16) and by Equation (17).

$$V_j^- = min_i\{V_{ij1}\} \tag{16}$$

The fuzzy negative ideal solution ($A-$) elements are as follows.

$$A^- = (V_1^-, V_2^-, .., V_n^-) \tag{17}$$

Step 4: According to the criteria of the alternatives, the distance values $A+$ to the fuzzy positive ideal solution and $A-$ to the fuzzy negative ideal solution are calculated. The distance of the fuzzy positive ideal solution $A+$ value is calculated by Equation (18).

$$d^{+} = \sum_{j}^{n} d\,(\bar{v}_j, \bar{v}_j^{*}) \quad i = 1,2,\ldots.,m \tag{18}$$

The distance of the fuzzy negative ideal solution $A-$ value is calculated by Equation (19).

$$d^{-} = \sum_{j}^{n} d\,(\bar{v}_j, \bar{v}_j^{*}) \quad i = 1,2,\ldots.,m \tag{19}$$

Equation (20) using the vertex method, d (…) is the measure of the distance between two fuzzy numbers..

$$d(\widetilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}}[(m_1 - n_1)^2 + +(m_2 - n_2)^2 + (m_3 - n_3)^2] \tag{20}$$

Step 5: The proximity coefficient CCi values for all alternatives are calculated by Equation (21).

$$CCi = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \tag{21}$$

The CCi value should be between [0, 1] shown in Table 3. As the CCi value approaches 1, A+ indicates that it is close to the ideal solution, while A- indicates that it is far from the ideal solution value. As the closeness coefficient value approaches 0, it shows that while A- is close to the ideal solution, it is far from A+ ideal solution value (Chen et al., 2006).

Table 3. Closeness coefficient evaluation

Closeness Coefficient (CCi)	**Assessment status**
CC_i ∈ [0,0.2)	Do not recommend
CC_i ∈ [0.2,0.4)	Recommend with high risk
CC_i ∈ [0.4,0.6)	Recommend with low risk
CC_i ∈ [0.6,0.8)	Approved
CC_i ∈ [0.8,1.0)	Approved and preferred

3. CASE STUDY

This study addresses the supplier selection challenge within the surface processes of a defense industry company. Through a simultaneous survey, three expert decision-makers evaluated four alternative suppliers against ten distinct criteria. This section presents an illustrative application. The study employed the Fuzzy AHP Chang Extended Analysis Method and Fuzzy TOPSIS Methods for evaluation. The criteria considered for supplier selection are as follows: price availability, return time for offers, diversity in field of activity, technical competence, production capacity, appropriate product ratio, prompt delivery, industry awareness, and customer relationship. The Fuzzy AHP analysis identified appropriate product ratio and prompt delivery as crucial factors in supplier selection. Furthermore, all alternatives were evaluated against these criteria, and the cumulative weight vector is presented in Table 4.

Table 4. Alternative assessments

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	∑Wi
Wi / Supplier	0.085	0.173	0.008	0.157	0.147	0.190	0.190	0.000	0.033	0.017	
A1	0.523	0.762	0.000	0.332	0.685	0.456	0.516	0.000	0.504	0.683	0.542
A2	0.000	0.000	0.041	0.000	0.000	0.336	0.179	0.439	0.198	0.000	0.105
A3	0.000	0.000	0.313	0.278	0.000	0.208	0.306	0.561	0.099	0.000	0.147
A4	0.477	0.238	0.646	0.391	0.315	0.000	0.000	0.000	0.198	0.317	0.207

According to the combined weights in Table 4, the best supplier ranking is A1-A4-A3-A2. According to the Fuzzy TOPSIS method; given in Table 5 di* and di- are calculated from the distances of the alternatives from FPIS and from FNIS for all criteria.

Table 5. di* and di- values of alternatives

	di*	di-
A1	2.627	8.084
A2	7.042	3.680
A3	6.381	4.363
A4	4.302	6.545

After calculating the distances from FPIS and FNIS, the closeness coefficients of each alternative are calculated using Equation (21) shown in Table 6. According to Table 3; A1 and A4 are approved suppliers, A2 is high risk and A3 low risk.

Table 6. Closeness coefficients

	CCI	Ranking
A1	0.755	1
A2	0.343	4
A3	0.406	3
A4	0.603	2

4. CONCLUSION

This study used a methodology in a fuzzy framework to evaluate the supply chain. Since many factors affect supplier selection, decision-makers are quite indecisive in their selection decisions. Fuzzy logic was used to minimize this uncertainty. Ten criteria affecting the selection were determined, and the most important criteria were the appropriate product ratio and fast delivery. Businesses need to give importance to supplier selection to make a profit. Supplier performance should be measured at regular intervals, and the suppliers' capabilities, the advantages they provide, and the characteristics of the suppliers should be checked. As a result of the application of Fuzzy AHP and Fuzzy TOPSIS methods, supplier rankings A1-A4-A3-A2 were the same from largest to smallest. According to the fuzzy TOPSIS method, A1 and A4 are acceptable suppliers, while A2 and A4 suppliers are in the non-preferred range.

Despite the similarities in outcomes produced by both methods, they diverge in certain aspects. For instance, the Fuzzy TOPSIS method considers the distances to both positive and negative ideal solutions as a basis for ranking alternatives. Conversely, the Fuzzy AHP method determines the priorities of alternatives by calculating synthesis values derived from pairwise comparisons. In prospective research, the study can be enhanced by employing methodologies tailored to address heightened levels of uncertainty, such as q-rung orthopair fuzzy-based approaches. The study's robustness can be assessed through the execution of various sensitivity and scenario analyses. Enhancing the study's robustness can be achieved by administering multiple surveys to decision-makers concurrently, as opposed to utilizing a single survey.

Conflict of Interest

The authors declared that there is no conflict of interest.

Contribution of Authors

All authors contributed to literature review, data collection, analysis and interpretation.

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